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LAWRENCE BERKELEY NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

Development and Deployment of Advanced Detector Systems from the Semiconductor Detector Laboratory

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Applied Nuclear Physics Program

Nuclear Science Division, Director's Review
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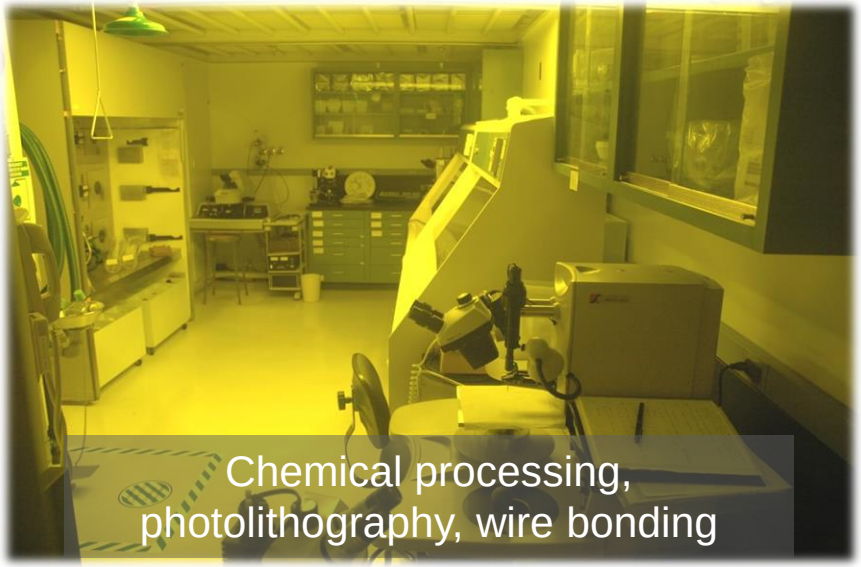
LBNL Semiconductor Detector Laboratory (SDL)


Thin-film deposition


Chemical processing, photolithography, wire bonding


Detector characterization

Infrastructure and expertise for the development and production of semiconductor-based radiation detectors and detection systems

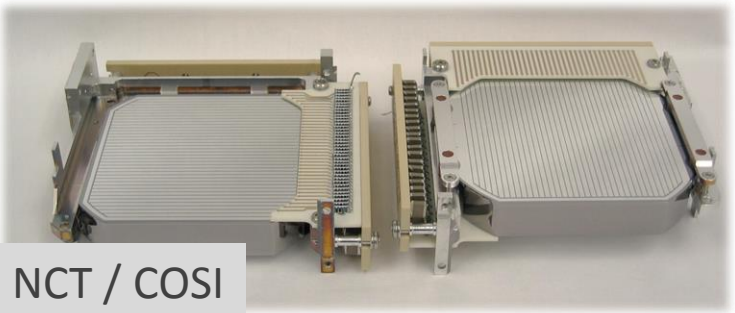
Detector Group at LBNL

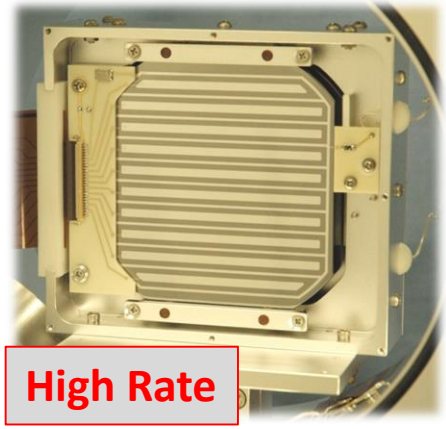
Historical accomplishments with significant impact to radiation detector technology:

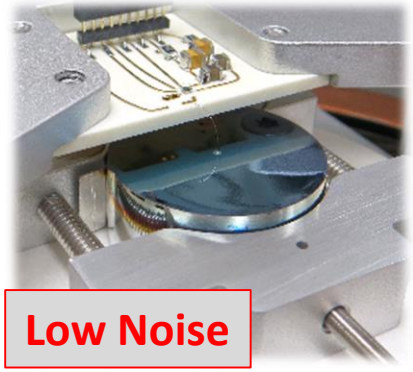
- One of first groups to develop lithium-drifted **Si:Li** detectors (early 1960's)
- One of two groups that originally developed high-purity Ge (**HPGe**) crystal growth (early 1970's)
- First Si and Ge **drift detectors** produced in our laboratories
- Fabrication technologies developed include: **amorphous semiconductor** contact, implanted contact, and surface passivation
- Developed position-sensitive Si and Ge **strip detectors**
- Invented shaped-field **point-contact Ge** detector (1989)
- Invented **coplanar-grid** technique for CdZnTe-based detectors (1994)
- Invented **proximity charge-sensing** readout technique (2009)
- Developed **low-noise** electronics for semiconductor detectors

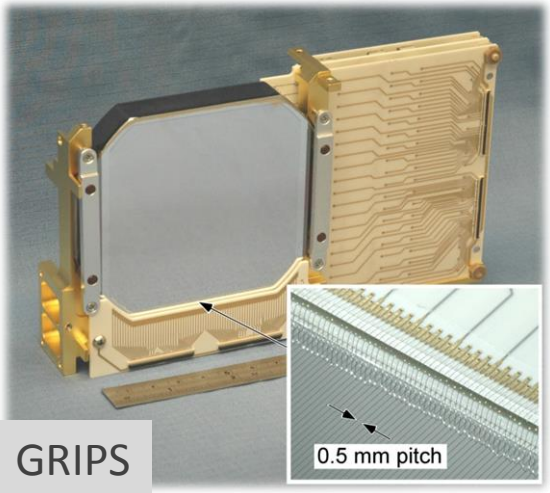
LBNL Semiconductor Detector Laboratory (SDL)
Ge Detector Technologies

Advanced detectors from HPGe crystals: segmented, high rate, low noise

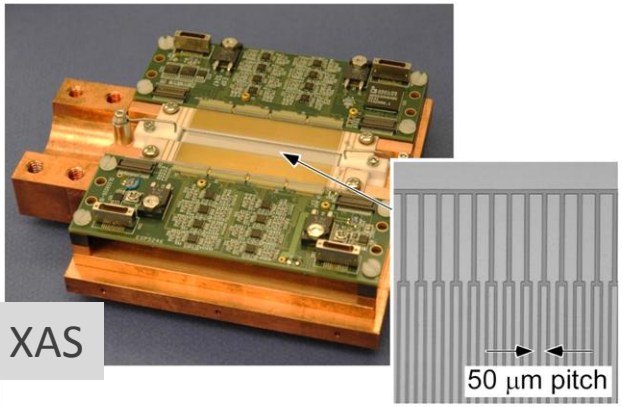

NCT / COSI


High Rate

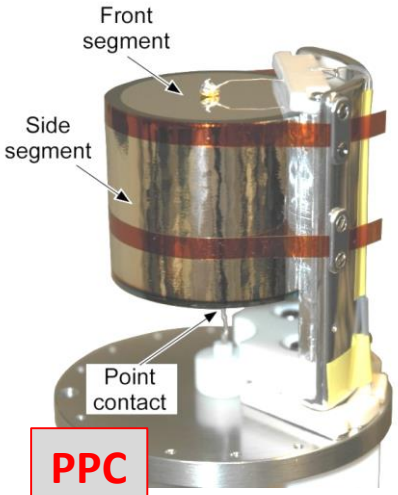

Low Noise



GRIPS



XAS



PPC

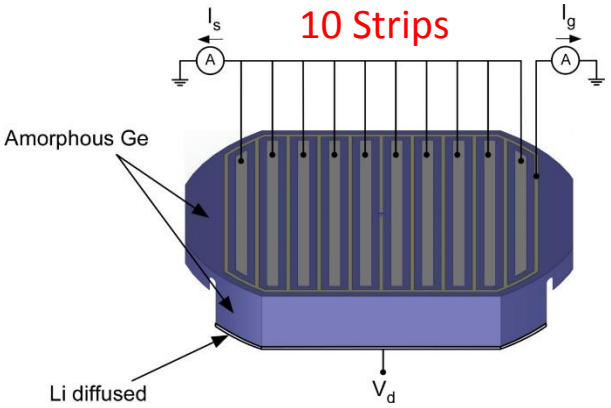
Advanced detectors require similar investment in readout integration.

High Rate Germanium

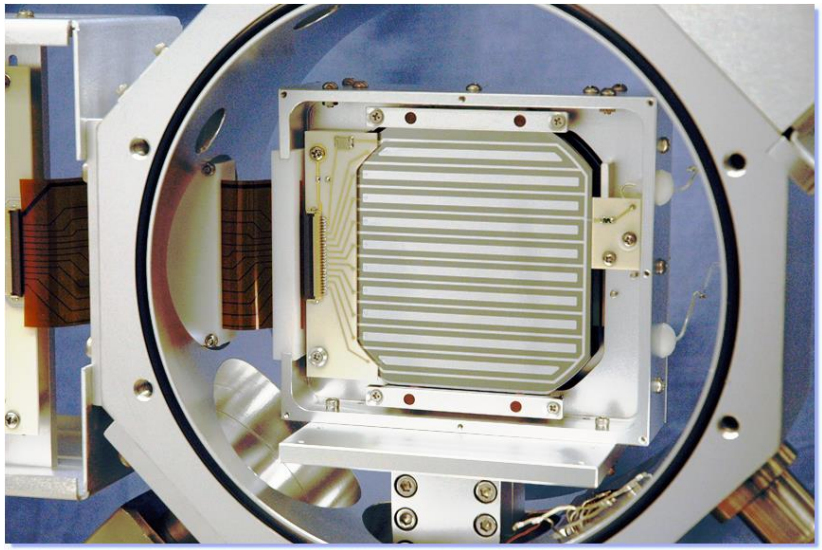
*funded by DOE NNSA

Primary Application:

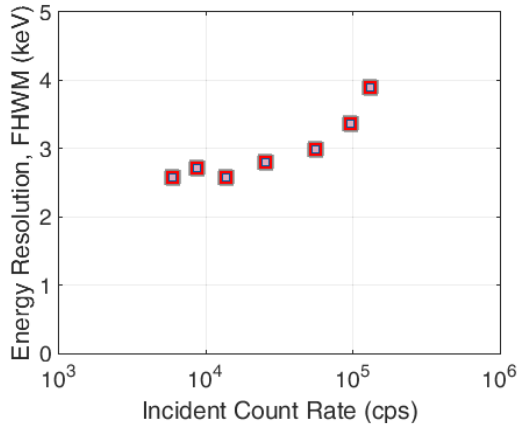
Spent nuclear fuel assay,
maintaining energy resolution at high rates

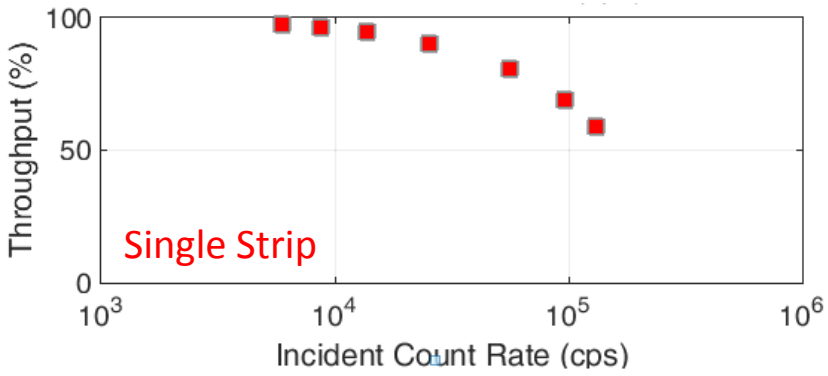


Optimized steering grid and strip capacitances.



Test cryostat for segmented high-rate Ge detector.



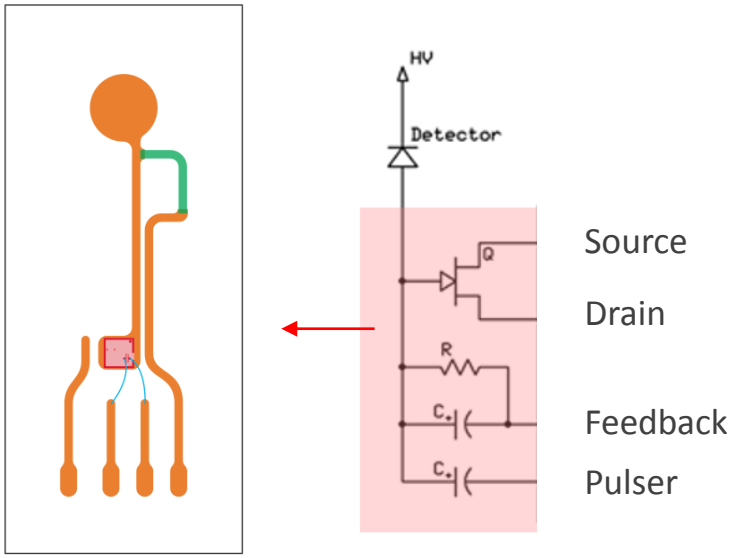


Towards: mechanically-cooled, ASIC-readout, signal decomposition.

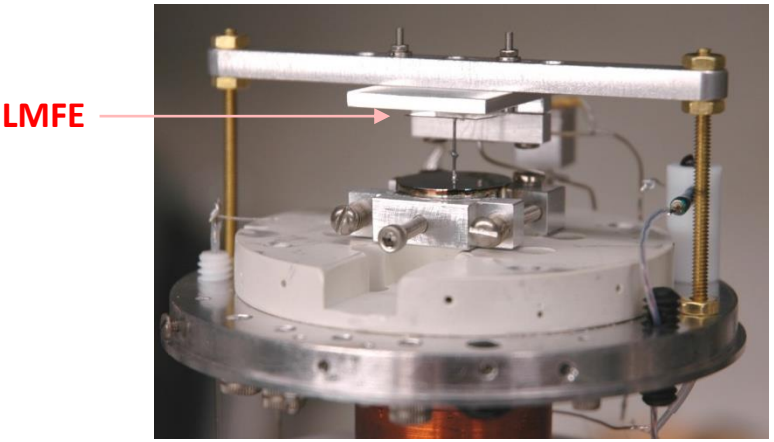
Low Mass Front End (LMFE) Readout Electronics for Point Contact HPGe

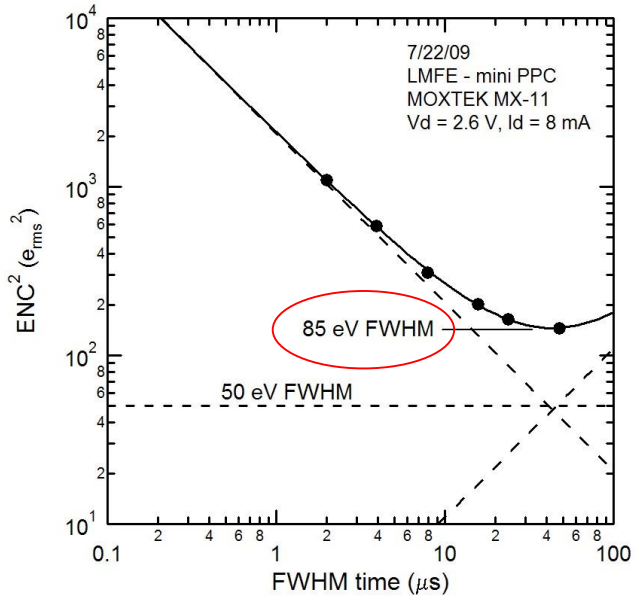
Key Features:

- Fused silica substrate
- Bare die low-capacitance JFET
- Amorphous Ge feedback resistor
- Au trace proximity capacitors



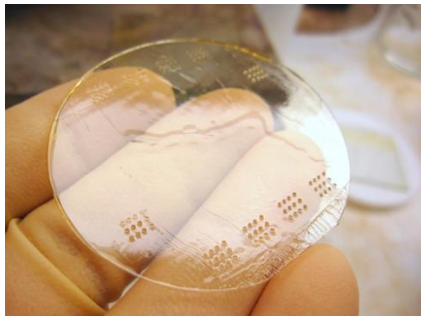
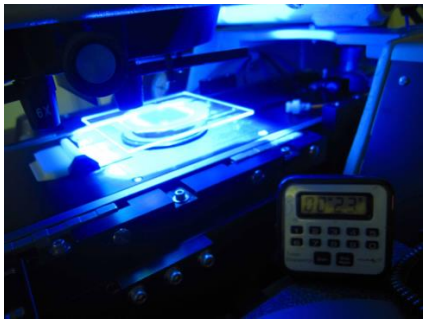
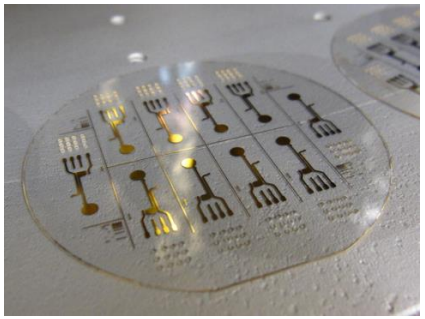
LMFE design for the MAJORANA Demonstrator

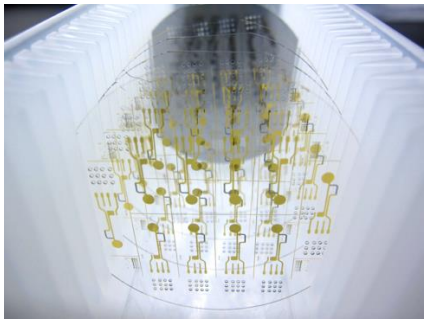
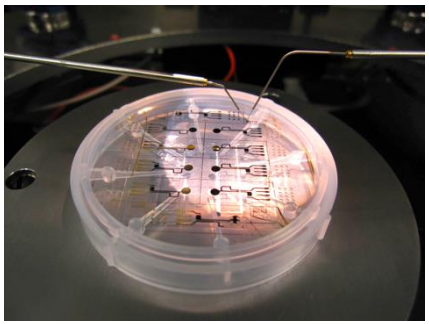


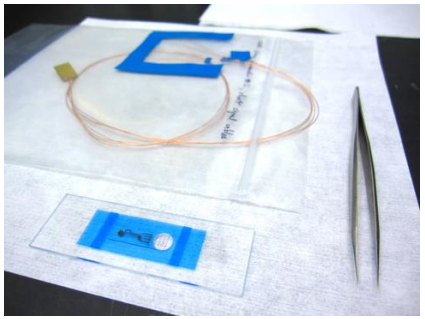
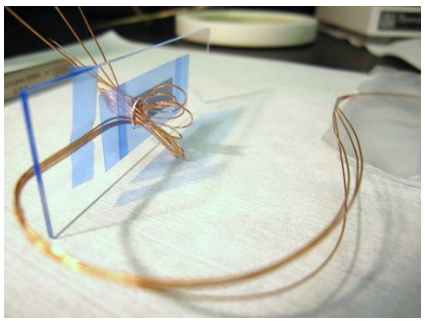


Initial concept developed by Paul Luke with LBNL LDRD

LMFE Fabrication at the SDL

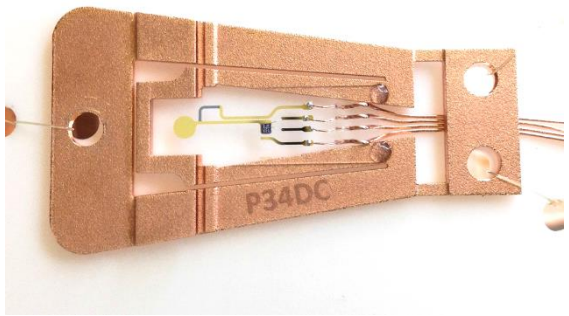




Low background thin film processing, testing and assembly of 150+ modules

MAJORANA Demonstrator Assembly



LMFE modules are carefully installed with a low-background pin to each detector's point contact, achieving 165 eV-FWHM electronic noise.

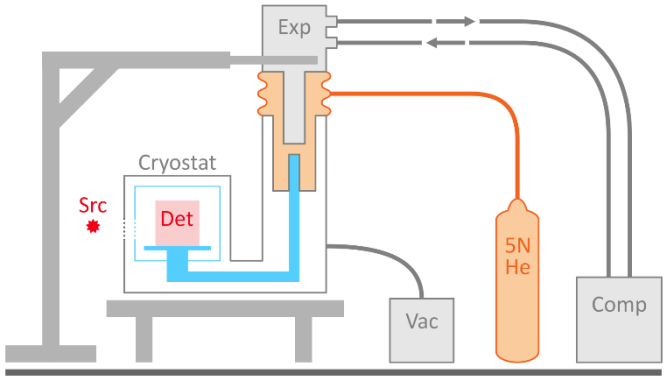
LMFE + detector assembly in radon-free glove box

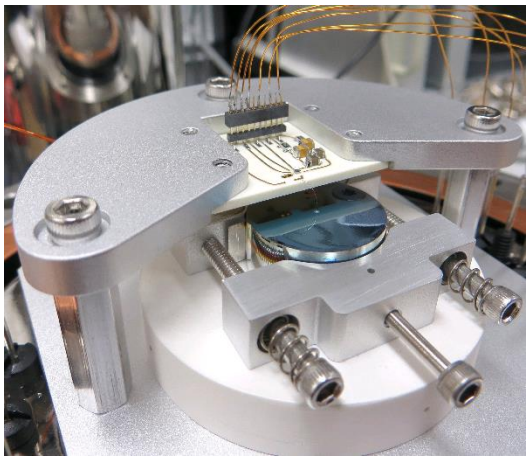
Sanford Underground Research Facility

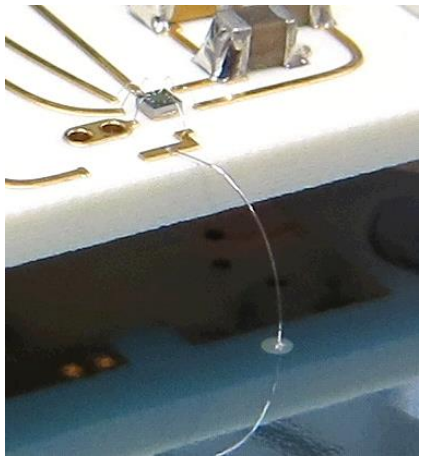
Ultra-Low Noise HPGe for Coherent Neutrino Nucleus Scattering

*Funded by DOE NNSA

The First: Mechanically Cooled, Wirebonded PPC HPGe, with CMOS Front End







Atmospheric Pressure He Gas

Provides ultra-low vibration thermal link using standard GM cycle (10 – 80 K)

→ Eliminates all vibrations

Ultra-Low Capacitance

Smaller point contact (0.26 pF) enabled by wire bonding

→ Ultra-Low Electronic Noise

Preamp-on-a-Chip

CMOS ASIC for SDD

4 electrons-rms noise

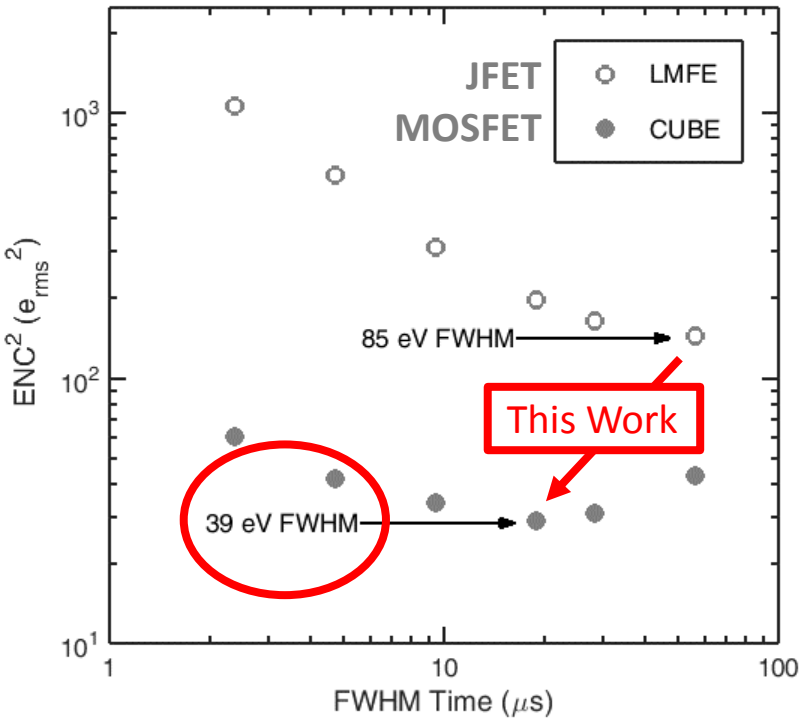
→ Better than JFET at low temperatures

Low temperature and **low capacitance** of CMOS and Ge.
Result: lowest noise HPGe detector: **39 eV-FWHM** at 40 K.

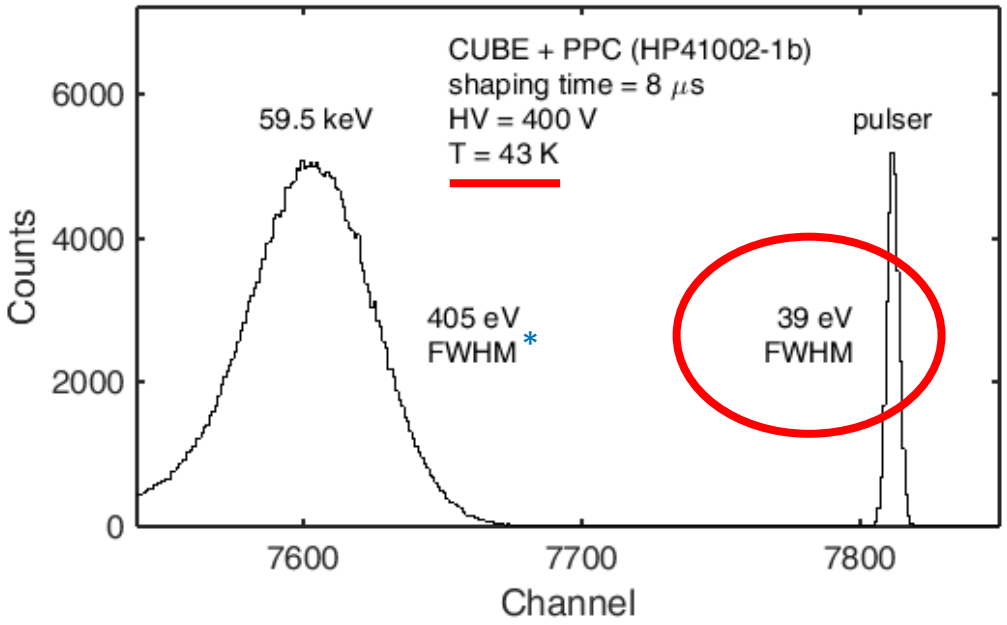
doi:10.1016/j.nima.2015.12.031

Ultra Low Noise Results from ULGeN Project

Equivalent Noise Charge



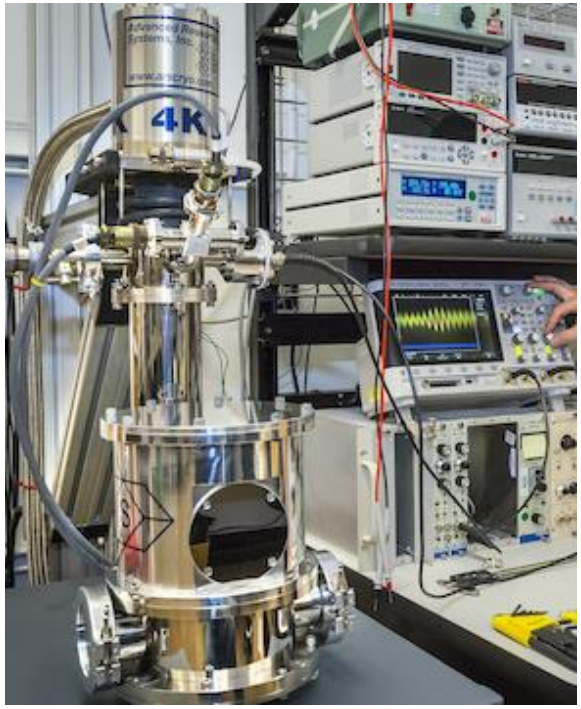
^{241}Am Spectrum with Pulser



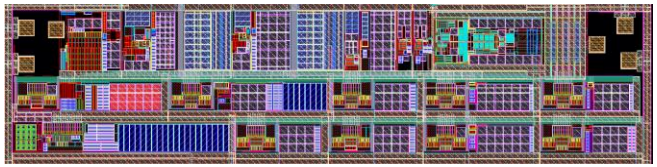
* 356 eV-FWHM (Fano limit) at 90 K

All noise components improved by combination of **low temperature** and **low capacitance**

Lower Noise Electronics for Coherent Neutrino Scattering



LNC (Low Noise / Capacitance) ASIC designed at BNL



ASIC Features:

1. Lower threshold
   (target <3 e-rms noise)
2. Low input capacitance
   (targeting 0.1 pF detectors)
3. Fewer connections (Pwr,Gnd,In,Out)
   (minimizes cabling + backgrounds)
4. On-board filters
   (reduces external components + backgrounds)

Ge Quenching Factor Measurement at TAMU (2016)

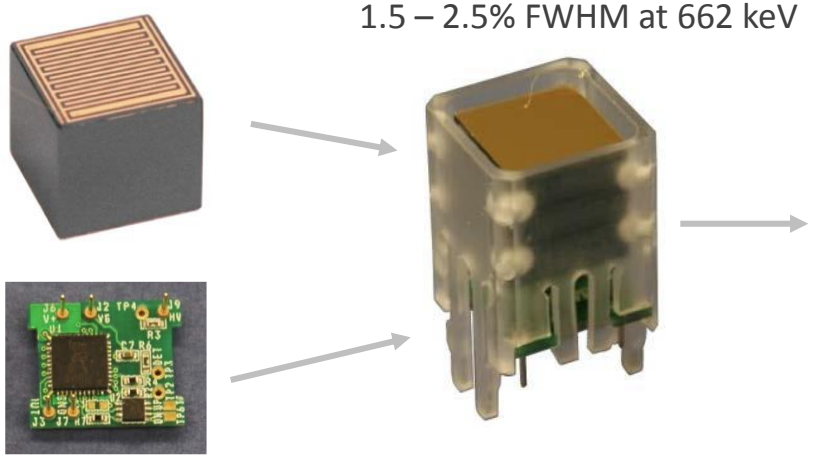
Ultra-Low Noise HPGe detector system moved to TAMU reactor and neutron beam to measure lowest energy nuclear recoil quenching factor.

Also supporting: low-energy program for ton-scale HPGe.

High Efficiency Multimode Imager (HEMI)

*funded by DHS DNDO

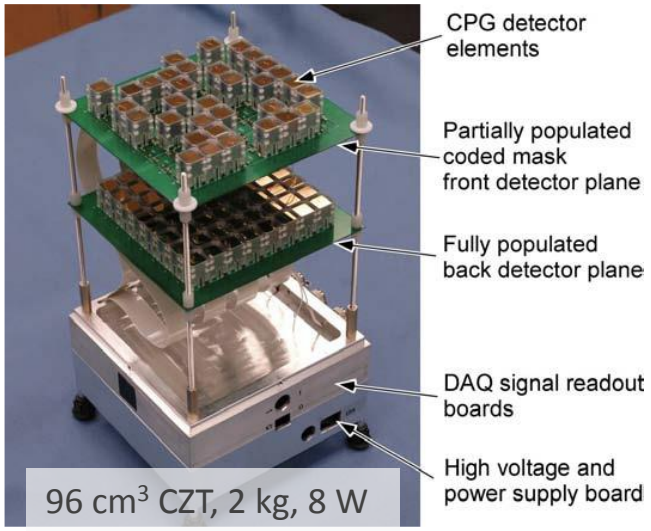
1.5 – 2.5% FWHM at 662 keV



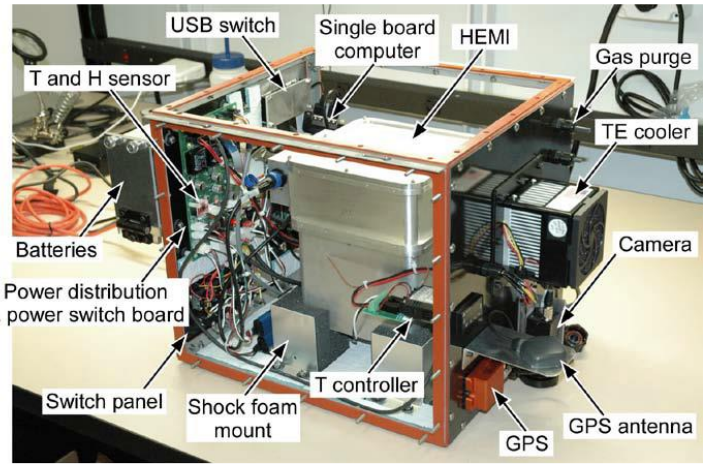
Coplanar-grid (CPG) CdZnTe pioneered by Paul Luke.
Packaged with BNL CPG ASIC

Coded Aperture + Compton Imaging

(30-3000 MeV)



Active-Mask HEMI Instrument



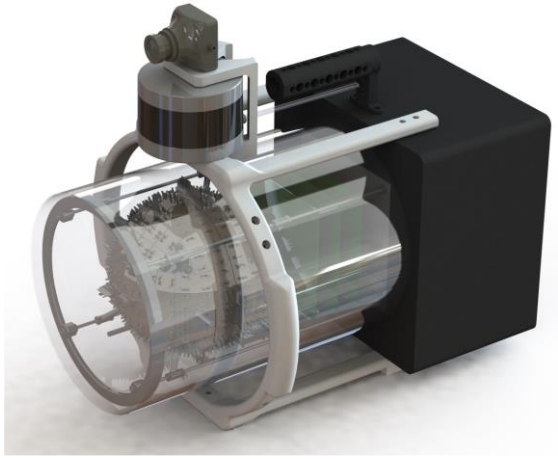
Ruggedized HEMI flight module

HEMI on RMAX helicopter flight in Fukushima

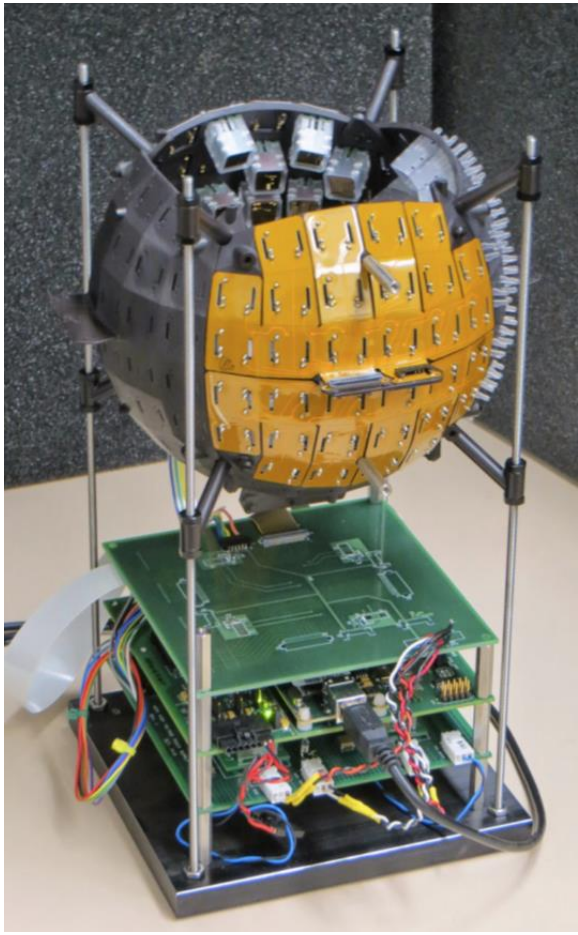
PRISM – A CdZnTe-Based Portable Radiation Imaging, Spectroscopy and Mapping System

*funded by DOD DTRA

HEMI with contextual sensors
(LIDAR, Camera)

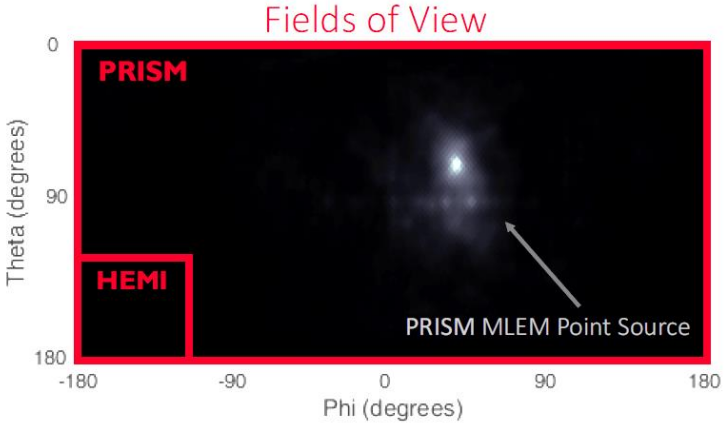


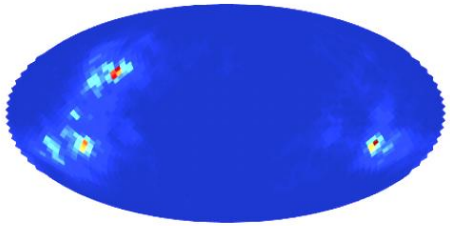
PRISM Prototype Concept
with spherical detector arrangement



PRISM Bench Prototype

First Spherical Coded Aperture Imager (simulations)





4π imaging of multiple
60 keV point sources

Advances and Opportunities for the NSD-Supported SDL

Advances

- Highly integrated HPGe strip detectors (0.5 mm pitch)
- High count rate HPGe strip detectors (> 1 Mcps)
- Lowest noise HPGe point contact detector (34 eV-FWHM)
- Fielded broad-energy CZT Imager (Fukushima & more)
- First “coded sphere” CZT Imager (4π coded aperture + Compton)

Opportunities

- **Mechanical cooling** integration for portable / reliable HPGe
- **CMOS integration** for strip and point contact HPGe detectors
- **CMOS integration** for portable CZT imagers